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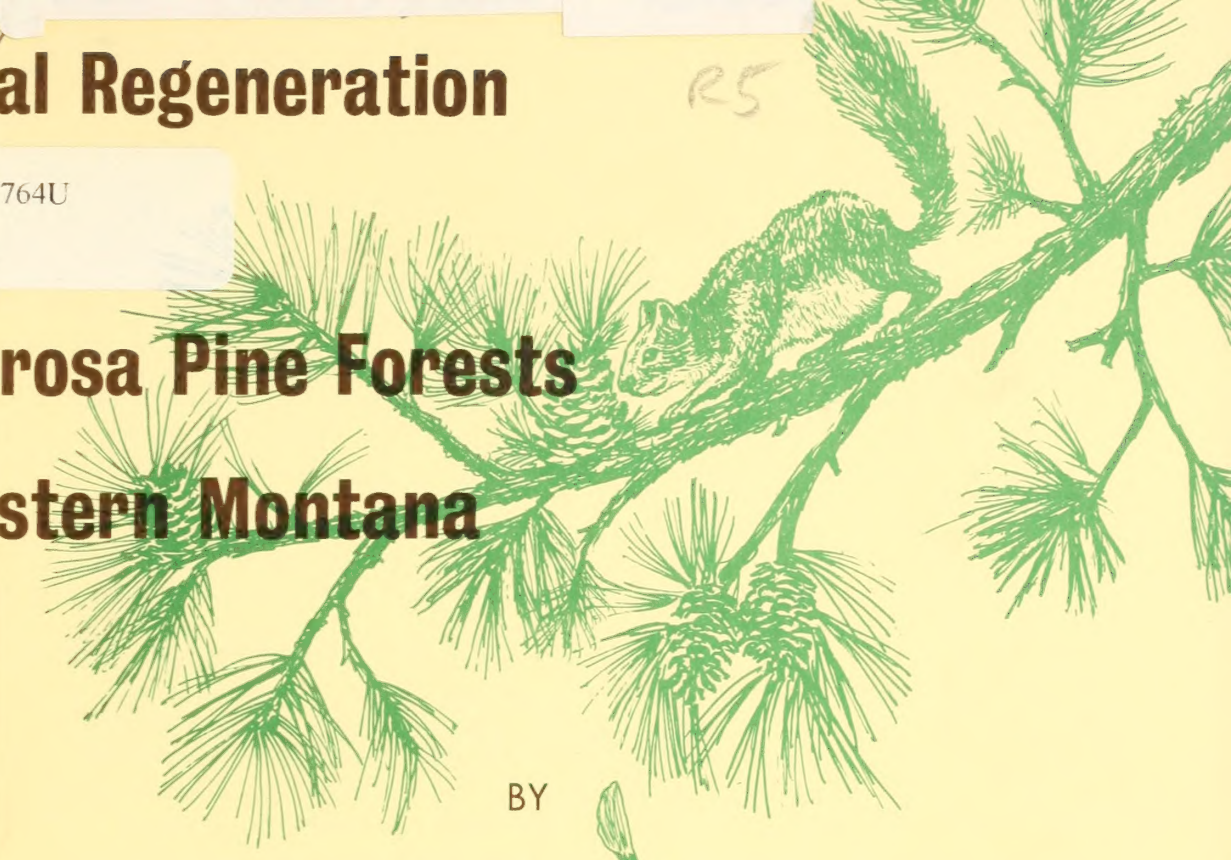
Natural Regeneration in Ponderosa Pine Forests of Western Montana



BY

RAYMOND C. SHEARER

WYMAN C. SCHMIDT

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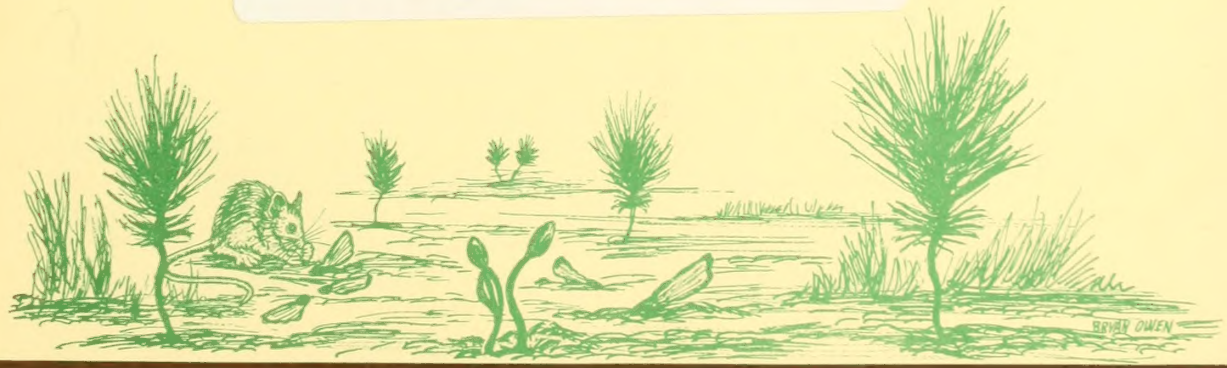

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION

Ogden, Utah 84401

THE AUTHORS

RAYMOND C. SHEARER received his B.S. degree in Timber Management from Utah State University in 1957 and his M.S. degree in Silviculture in 1959. Since 1957 he has been an Associate Silviculturist, assigned to the Station's Silviculture of Western Larch and Engelmann Spruce research work unit at the Forestry Sciences Laboratory at Missoula, Montana. His primary assignment has been the study of natural and artificial regeneration of western larch and associated species.

WYMAN C. SCHMIDT is Associate Silviculturist and Leader of the Silviculture of Western Larch and Engelmann Spruce research work unit at the Forestry Sciences Laboratory in Missoula, Montana. After 1 year with the National Forest Administration in the Black Hills, he joined the Intermountain Station in 1960 and since then has worked primarily in research of young coniferous forests. He holds B.S. and M.S. degrees in Forest Management and is currently completing requirements for the Ph.D. in Forest Ecology at the University of Montana.

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NATURAL REGENERATION IN PONDEROSA PINE FORESTS OF WESTERN MONTANA

Raymond C. Shearer and Wyman C. Schmidt

INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
Forest Service
U. S. Department of Agriculture
Ogden, Utah 84401
Joseph F. Pechanec, Director

ABSTRACT

At eight locations in western Montana some factors limiting the success of ponderosa pine natural regeneration were identified. During the 45-month period from ovulate bud formation until the seedlings were 1 year old, the potential decreased a thousandfold. Losses were attributed mainly to abortions and squirrel cutting during the 2-year cone development period and to mice and chipmunks during the 8-month period from seedfall to germination. Mineral soil seedbed enhanced the survival of young seedlings. These results showed that cone production in 50-year-old trees was temporarily stimulated by girdling, that squirrel losses can be eliminated by banding trees with metal strips, and that prospective cone crops can be detected early enough to permit the coordination of site preparation with an adequate seed crop.

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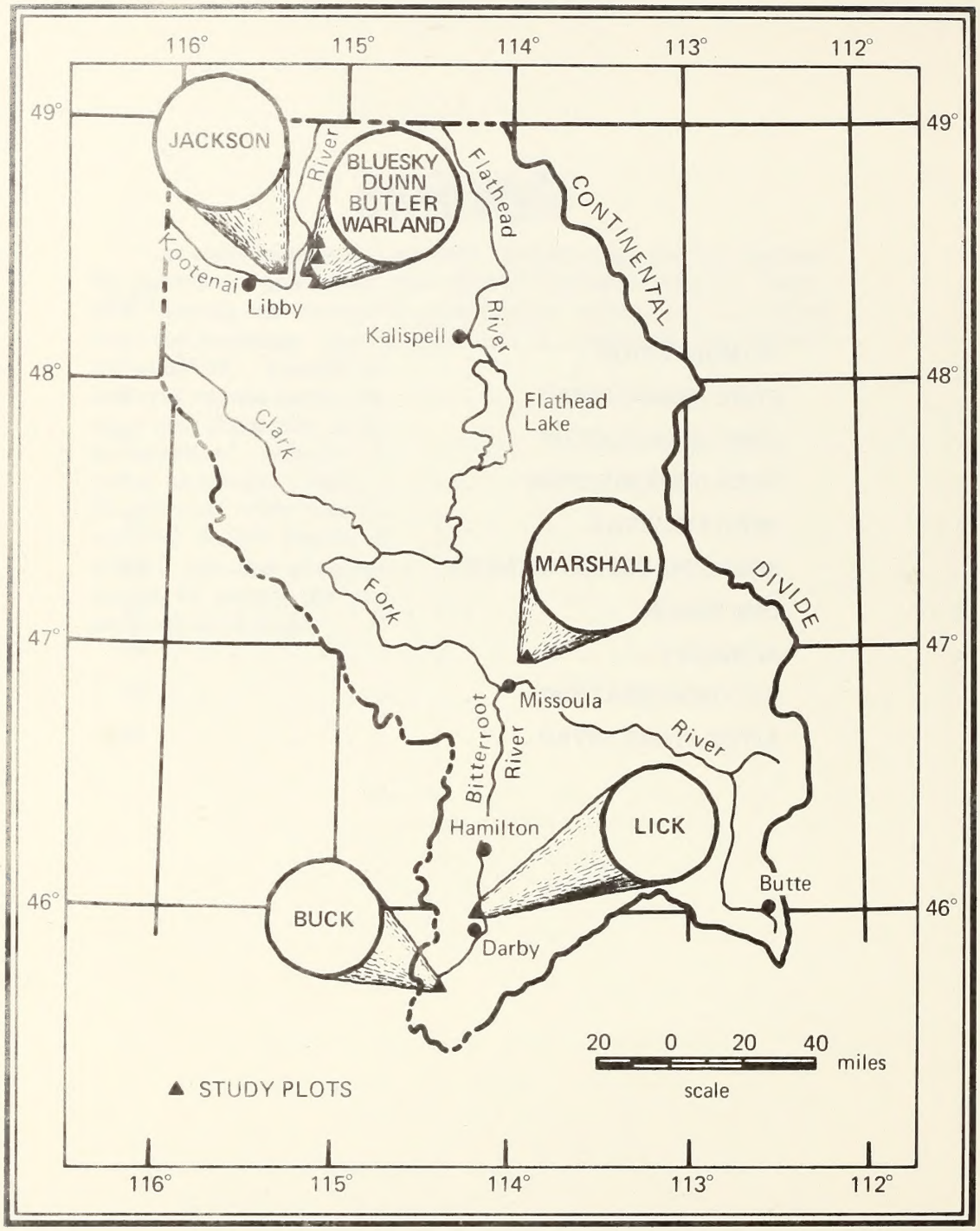

Figure 1.--Location of natural regeneration studies of ponderosa pine in western Montana.

INTRODUCTION

Following harvest cutting, natural regeneration of ponderosa pine (*Pinus ponderosa* Laws.) in western Montana usually is uncertain. Therefore, forest managers frequently rely on planting to promptly regenerate ponderosa pine and prevent future gaps in volume production. When the forester decides to restock an area by natural regeneration, he must effectively manipulate the factors under his control that influence seedling establishment.

Good ponderosa pine seed crops occur at irregular intervals (USDA Forest Service 1965); thus, timing of site preparation to coincide with seed production is a critical requirement for successful natural regeneration. Once cones are initiated, it is important to understand the factors influencing their survival. In addition, stimulation of cone production by girdling or release of seed trees would be a useful tool if ponderosa pine responds to either of these treatments.

Even when a sufficient seed crop is produced, the success of natural regeneration is further influenced by: (1) dissemination to a favorable seedbed; (2) seed loss to biotic agents; (3) germination of the remaining seed; and (4) survival of germinated seedlings.

All of these facets of natural regeneration were studied in western Montana from 1948 to 1962. Five studies were conducted at eight locations (fig. 1). The factors studied on each area are shown in table 1.

Table 1.--*Factors studied that influence natural regeneration of ponderosa pine in western Montana by study area*

Study area	Cooperators	Factors studied				
		Cone production	Cone stimulation	Seed dispersal	Seed survival	Seedling establishment
Northwestern Montana						
Bluesky Creek	Kootenai N.F.	[1]X		X	X	X
Butler Creek	St. Regis Paper Co.	[2]X		X	X	X
Dunn Creek	St. Regis Paper Co.	[2]X		X	X	X
Jackson Creek	Kootenai N.F.					X
Warland Creek	Kootenai N.F.					X
Southwestern Montana						
Buck Creek	Bitterroot N.F.		X	X		
Lick Creek	Bitterroot N.F.		X	X		
Marshall Creek	Anaconda Forest Products and Lolo N.F.		X	X		

[1]Complete evaluation of cone development and loss.
[2]Squirrel cutting.

The study plots, ranging from 5 to 50 percent in steepness, were located on south- or west-facing slopes lying between 3,000 and 3,900 feet elevation. Although ponderosa pine was dominant, Douglas-fir, its chief associate, was climax for these areas. The habitat types (Daubenmire and Daubenmire 1968) on each of the study plots were as follows (in order of decreasing moisture):

Bluesky - *Pseudotsuga menziesii* - *Physocarpos malvaceus* (moistest)
Warland - *Pseudotsuga menziesii* - *Calamagrostis rubescens*, *Arctostaphylos uva-ursi* phase (includes *Symphoricarpos albus* and *Spirea betulifolia*)
Jackson and Dunn - *Pseudotsuga menziesii* - *Calamagrostis rubescens*, *Arctostaphylos uva-ursi* phase (includes *Spirea betulifolia*)
Butler - *Pseudotsuga menziesii* - *Calamagrostis rubescens* (driest)

The soils developed in glacial till deposits. Silty volcanic ash mixed with local colluvial materials in the upper horizons while the horizons below 8 to 15 inches were of older colluvium. The soils were classified as Typic Cryandept at Bluesky and Warland, Mollic Cryandept at Jackson, and Typic Cryoboralf at Dunn and Butler. All were silty and loamy. Site quality class averaged IV or V for ponderosa pine by Meyer's (1938) classification.

Because there were studies on eight areas, the methods and results are presented in the natural sequence of events under the five main headings: (1) cone production; (2) cone stimulation; (3) seed dissemination; (4) seed survival; and (5) seedling establishment.

CONE PRODUCTION

Roeser (1941) studied ponderosa pine seed development, in central Colorado, from flowers to the mature cones. He found that an average of only about 1/4 of the pistillate flowers ultimately developed into mature cones; most of the mortality occurred in the first season of cone development. Further studies on development of ponderosa pine cones from the initial ovulate bud were made in western Montana to identify these factors that limit cone production and are reported here.

Methods

Eight sample trees, at least 16 inches d.b.h., were randomly selected for study in a partially cutover ponderosa pine stand at Bluesky (fig. 1). A total of 100 branches in the upper portion of the crowns of the trees (10 to 15 branches per tree) were systematically selected. Losses of buds, conelets, and mature cones were described by total number and apparent cause on each individually-marked branch; this description was made for each stage of cone development. The trees were climbed and data recorded four to seven times during the two-year cone-development periods for each of the cone crops that matured in 1953 through 1956.

In addition, a banding experiment was conducted to measure the effects of squirrels on seed production. To prevent squirrels from climbing the cone-bearing trees on the study plot at Dunn, all trees were protected in 1953 by 20-inch-wide aluminum bands. Stands used as check plots were not banded on the nearby Butler study area. In late 1953 four banded and four unbanded trees were climbed and the effectiveness of bands evaluated. Differences in seedfall at Dunn and Butler were measured by 20 seed traps on each of these two areas.

Results

Cone Mortality

Following bud formation, the number of developing pine cones decreased continuously until seed dissemination 2 years later. An average of only 6 percent of the ovulate buds matured and shed seed (table 2). Four cone crops, one rated fair (1954) and three rated poor (1953, 1955, and 1956), quantified these losses.

The percentage of cone survival was highest following the formation of the largest number of ovulate buds. The 1954 crop (rated fair) had 9 percent survival, but the 1955 crop (poorest of the 4 years) had no survival.

Seventy percent of the potential cones aborted (table 2), 64 percent during the first season and 6 percent during the second season. Squirrels reduced the potential cone crop an additional 14 percent and all other factors caused an additional 10 percent loss.

First Year of Development

An average of only 27 percent of the potential cone crop survived the first year of development. At the beginning of the first season, 5 percent of the buds failed to open. Following this, 64 percent of the cones aborted during the first season. Causes of these heavy losses from bud failure and abortion were not identified. Squirrel cuttings accounted for 2 percent of the first-year losses. Insects and other miscellaneous factors accounted for the remaining losses.

Second Year of Development

Only 23 percent of the pine conelets that survived the first year persisted until seedfall. During the second year an additional 6 and 12 percent of the potential cones aborted or were cut by squirrels, respectively. Insects and other miscellaneous factors accounted for the remaining losses. Consequently, only 6 percent of the buds matured and released seed at the end of the second year of development.

Table 2.--*Cause and amount of cone mortality during the 2-year development period*

Year of seed maturity	Ovulate buds	Bud failure	Abortions	Squirrel cutting	Insect loss	Miscellaneous loss	Cones surviving and shedding seed
	Number			*Percent*			
1953	292	-	65	24	6	2	4
1954	648	4	79	5	1	2	9
1955	67	24	72	0	0	4	0
1956	102	19	26	47	8	0	1
All years	1,109	5	70	14	3	2	6

Effect of Douglas-fir Seed Supply

Douglas-fir seeds, when available, also constitute an important segment of the pine squirrel's diet. In 1954, squirrels left many more cones on the trees than in 1953 or 1956, most likely because a fair number of ponderosa pine cones were available and Douglas-fir produced a bumper seed crop that supplemented the food supply. In 1956, all but one pine cone was harvested before the seed could be dispersed. This was probably due to the absence of Douglas-fir cones.

Squirrel Cutting

The tree-banding experiment provided additional information about squirrel effects on seed production. Four trees with aluminum bands at Dunn produced 84 cones that shed seed. Three shoots were cut before the bands were installed. The unbanded trees at Butler still retained 58 cones at the time of seedfall, but careful examination revealed that 16 cones and 39 shoots were cut by squirrels.

Seed production from trees that had been banded in the Dunn area was more than three times greater in 1953 (9,300 seeds per acre) than it was in 1951 (2,800 seeds per acre), before these trees had been banded. Seed production from trees that had not been banded in the Butler and Bluesky areas, however, remained about the same: in the Butler area, it was 1,600 in 1951 and 1,700 in 1953; in the Bluesky area, it was 10,300 in 1951 and 10,400 in 1953.

Cone Crop Forecasting

At times it is desirable to forecast cone crops for purposes of timing seedbed preparation or scheduling seed tree removal. This can be done by examining branches in the upper half of the crown 2 years before a ponderosa pine seed crop will be disseminated. Data from this study indicate that when the number of ovulate buds average one or less per branch, few conelets will survive the period between bud formation and first-year cone development. Any that do survive are highly vulnerable to squirrels that are faced with a short food supply during the second year of cone development. The poor seed crops of 1953 and 1956 resulted from three or less ovulate buds per branch. The fair cone crop in 1954 was initiated by an average of six to seven ovulate buds per branch. It is likely that 10 or more ovulate buds are required per branch to produce a good ponderosa pine seed crop.

If management planning can be delayed until 1 year prior to seed release, then the observer, by counting the first-year conelets, can make a more accurate estimate of the potential seed crop. This study showed that when less than one conelet remained per branch after one year, a poor seed crop resulted. Fair seed crops resulted when more than one conelet remained at the end of the first year of development.

The number of Douglas-fir cones maturing at the same time as the ponderosa pine cones probably influences the number of pine cones taken by squirrels. A good Douglas-fir crop provides a readily available source of food for squirrels. Apparently, the squirrels respond by feeding less heavily on the pine and a fair cone crop of pine may mature. When an alternate source of food is not available, the squirrels usually feed heavily on pine and reduce its production.

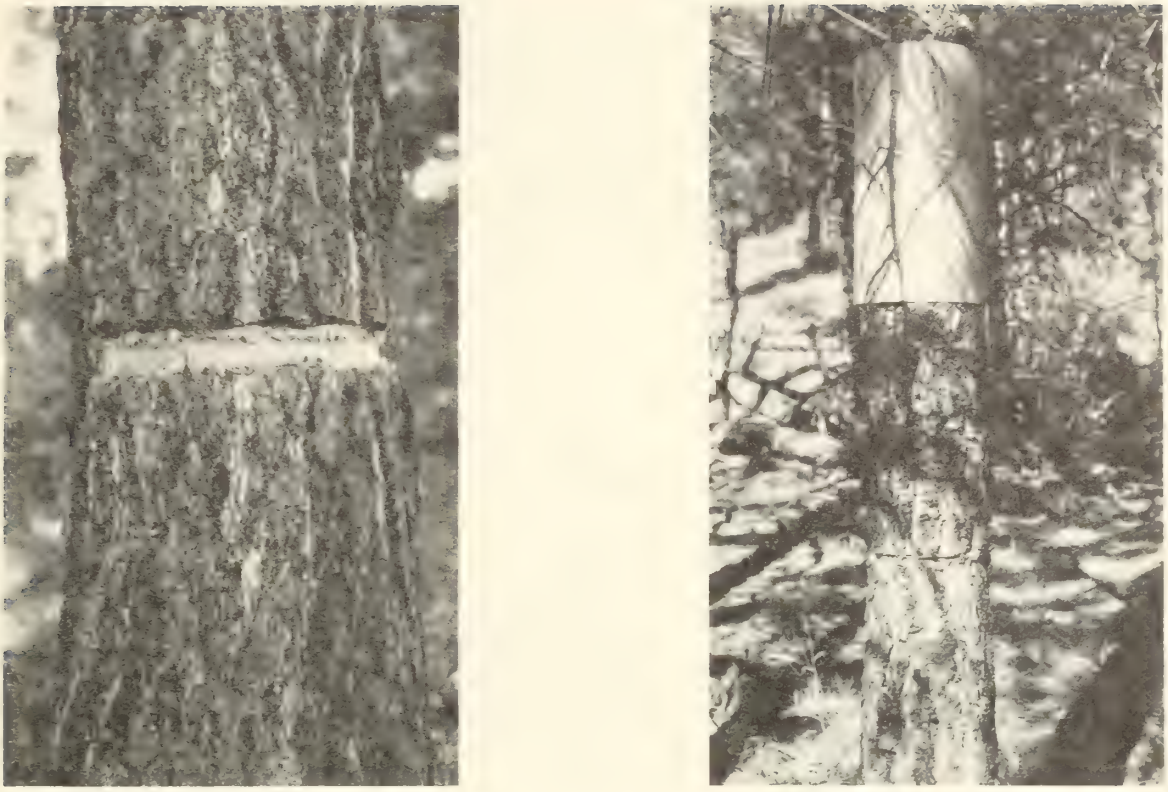

Figure 2.--Methods of girdling used: (A) In the wide girdling method, a 1- to 2-inch strip of bark and cambium was removed except for a 2- to 4-inch bridge left intact. (B) In the narrow girdling method the bark and cambium was cut through and around the entire bole circumference. Note the installation of a 12-inch-wide aluminum band to prevent squirrels from girdling the tree.

CONE STIMULATION

Girdling and release has increased cone production in other pine species (Holmes and Matthews 1951; McCulley 1953; Wenger 1953a, 1953b; Godman 1962). These methods were also used in an attempt to stimulate cone production of ponderosa pine in western Montana.

Methods

Wide girdling (fig. 2a) of 15 trees (five each of immature, mature, and overmature trees) and narrow girdling (fig. 2b) of five immature trees was completed at Lick in May 1954. Wide girdles were made by removing a 1- to 2-inch strip of bark and cambium except for a 2- to 4-inch bridge left intact. Narrow girdles were made by a cut through the bark and cambium around the entire bole circumference. Each girdled tree was paired with a nearby untreated but morphologically similar tree.

Release of individual trees as a means to stimulate cone production was tested by removing competition within a radius of 12, 20, and 25 feet around immature, mature, and overmature trees (five of each). These release conditions were established for the immature trees in May 1954 at Lick and for the mature and overmature trees in May and June 1955 at Buck. Response to release was evaluated by pairing each treated tree with a nearby untreated tree. All of these trees were banded with 16-inch-wide metal strips to prevent squirrels from climbing the trees.

The average ages and sizes for girdled and released trees were:

Age (Class)	Age (Years)	D.b.h. (Inches)	Height (Feet)
Immature	50	9	42
Mature	140	18	78
Overmature	220	25	98

Results

Girdling

Both wide and narrow girdling of 50-year-old ponderosa pines increased cone production of the first crop formed after treatment (table 3). Even though the analysis of variance showed a statistically significant (1 percent level) increase overall, about 20 percent of the trees showed no effects of treatment. Trees with either of the girdling treatments produced an average of over 20 cones per tree in 1956 while their untreated counterparts averaged only one cone per tree. In the years following the first crop, there were no significant cone-production differences between treated and untreated trees.

Wide girdling of 140- and 220-year-old pines prompted no statistically significant increase in cone production, but cone production from about half of the treated trees did increase considerably in 1957 which was the first cone crop that could have been affected by the girdling (table 3). Narrow girdling was not tried on these older trees.

Girdling usually did not change the subsequent appearance of the trees. In 1956, 2 years following treatment, two trees had slight yellowing of the foliage, but these improved later. No comparisons were made to see if girdling affected increment.

Table 3.--*Average cone production by age class on girdled and check trees before and after treatment*

Year	50-year age class		140- and 220-year age classes combined	
	Girdled	Check	Girdled	Check
	Cones per tree[1]			
1954	12	17	124	110
1956	[2]22	[2]1	100	70
1957	2	1	[2]118	[2]60
1958	37	28	150	148
1959	2	2	2	1

[1]Based on five 50-year-old trees, five 140-year-old trees, and five 220-year-old trees. The 140- and 220-year age classes were combined because they did not differ significantly.

[2]First possible cone crop that could have been affected by the girdling treatments.

Table 4.--*Average cone production by age class on released and check trees before and after treatment*

Year	50-year age class		140- and 220-year age classes combined	
	Release	Check	Release	Check
	Cones per tree			
1954	1	3	7	13
1956	1/ 1	1/ 1	30	20
1957	1	1	1/ 2	1/ 8
1958	10	3	62	106
1959	1	1	1	1

[1]First possible cone crop that could have been affected by the release treatment.

Release

Release from nearby competing trees did not increase cone production significantly during the two or three cone crops following treatment (table 4). Large between-tree-variation prevented any meaningful results.

Tree Age

The 140- to 220-year old trees produced about eight times more cones than the 50-year-old trees. The 5 years of record showed that the older trees yielded an average of 60 cones per tree, while the younger trees averaged only seven cones per tree. One mature tree produced 342 cones in 1958, a good seed year. Complete cone production failures were rare on the individual trees of the two older age classes. About three-fourths of these trees produced at least a few cones every year. Failures were much more common, occurring over 50 percent of the time, in the younger individuals.

SEED DISSEMINATION

Of 22 reported ponderosa pine cone crops in western Montana from 1908 to 1953, only one was rated good, but five others were rated fair (Boe 1954). During these same years, three Douglas-fir cone crops were rated good and nine were rated fair (Boe 1954). Boe (1954) concluded that pine was a poor seeder and Douglas-fir a prolific seeder in western Montana. This study provided additional data for evaluation of seed crops.

Methods

Seed crop variability and time of seedfall in partially-cut ponderosa pine and Douglas-fir stands were studied at five locations from seed trap collections made two to six times annually. These were sampled as follows:

Areas	*Years of collection*	*Size of seed trap*	*No. of seed traps*
Bluesky	1948-1955	1/4 milacre	20
Dunn & Butler	1952-1955	1/4 milacre	20
Marshall & Buck	1954-1958	1 sq. ft.	30

The relationship of seed production to varying stand volumes was also included in the observations at Bluesky. Half of the seed traps in Marshall and Buck Creek were in uncut stands.

Results

Yearly Variation (Periodicity)

Good ponderosa pine cone crops were produced in 1948 and 1958 and a fair crop developed in 1954 (table 5). Douglas-fir produced good crops in 1954 and 1958 and a fair crop in 1949. Poor or near-failure crops characterized all intervening years. Although good or fair crops were dispersed by both species in 1954 and 1958, ovulate bud formation was not correlated between the two species because pine and fir require a 2- and 1-year development period before seedfall, respectively.

The percent of filled pine and fir seeds increased with cone production (table 5): however, the pine maintained higher soundness than the fir. The good, fair, poor, and near-failure pine crops averaged 75, 69, 53, and 14 percent soundness, respectively; the fir averaged only 43, 25, 13, and 10 percent filled seeds.

Seasonal Variation (Timing)

Sound (filled) pine and fir seeds generally fell earlier than the hollow seeds. Dispersal of sound pine seed was 90 percent complete about a month before the total seedfall reached the same point. Squillace and Adams (1950) previously reported that 78 percent of the pine seed that fell in September 1948 was sound, but only 50 percent was filled in later collections. Usually ponderosa pine and Douglas-fir seedfall began about the first of September and peaked in mid-September. Most of the seed was shed by the end of October. However, some hollow seeds continued to fall throughout the winter.

Table 5.--*Average number and percent of sound ponderosa pine and Douglas-fir seeds dispersed in five cutover stands of western Montana from 1948 to 1958*

Year	Ponderosa pine			Douglas-fir		
	Number	Percent	Ranking	Number	Percent	Ranking
	Thousands/ acre			*Thousands/ acre*		
1948	76	73	Good	4	11	Poor
1949	8	38	Poor	80	25	Fair
1950	([1])	8	Poor	4	12	Poor
1951	10	63	Poor	0	0	Poor
1952	([1])	20	Poor	([1])	29	Poor
1953	7	57	Poor	10	15	Poor
1954	42	69	Fair	229	41	Good
1955	0	0	Poor	1	4	Poor
1956	0	0	Poor	0	0	Poor
1957	0	0	Poor	0	0	Poor
1958	135	76	Good	232	46	Good

[1]Less than 500 sound seeds per acre.

SHEARER RAYMOND C. and SCHMIDT WYMAN C.

1970. Natural regeneration in ponderosa pine forests of western Montana. USDA Forest Serv. Res. Pap. INT-86, 19 p., illus.

The potential for establishment of ponderosa pine seedlings in western Montana decreased a thousandfold during the 45-month period from ovulate bud formation until the seedlings were 1 year old. The probability of successful natural regeneration is increased by protecting cones from squirrels, by reducing the population of ground-dwelling rodents, and timing site preparation with expected cone crops.

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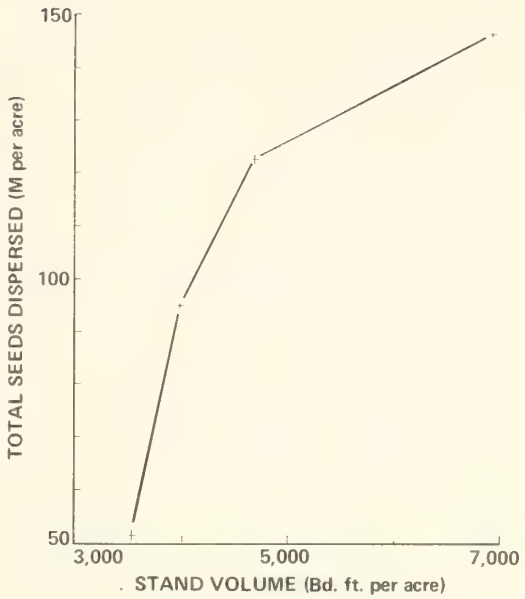
Figure 3.--Relationship of reserve stand volume to the total number of seeds dispersed per acre. The trees ranged from 12 to 27 inches d.b.h. and averaged 19 inches d.b.h.



Seedfall was influenced by the climatic conditions prevailing during the time cones matured and seeds were shed. For example, in 1951, 90 percent of the sound pine seed was dispersed by October 1. This was due to the near normal rainfall and temperature that prevailed during August 1951. However, in 1954 only 70 percent of the sound seed was shed by October 1 because summer rainfall was heavy and temperatures remained well below average. Conversely, seedfall began earlier in 1949 because of dry, warm conditions.

Stand Volume

Seed production of ponderosa pine at Bluesky was directly related to residual volume in 1948, a good seed year (fig. 3). This relationship was not consistent in years of lower seed production and varied between areas from year to year. These differences may have been caused by unequal cone losses before seed dispersal or the sample may simply have been too small to detect any trend.

SEED SURVIVAL

Large numbers of ponderosa pine seeds are usually destroyed on the ground prior to spring germination. Seeds lost to rodents and other factors during the period from dispersal to germination were determined at Bluesky (1948-1951, and 1953) and at Dunn and Butler (1951, 1953, and 1954).

Methods

From 10 to 39 quarter-milacre duff samples were taken next to seed traps in May of each year to study the number of unprotected seeds remaining over winter. The differences between numbers of seed caught in the traps and the numbers found on these duff plots represented the take by rodents and other seed destroying agents.

Sunflower seeds coated with thallium sulphate were used to poison rodents and protect the seed at the Dunn and Butler plots in early September 1951. Also, a 1000-foot buffer zone was treated on each side of the plots.

Results

Most of the pine and fir seed that reached the ground were destroyed prior to germination. Squillace and Adams (1950) reported early in the study period that only 8 percent (5,800 seeds per acre) of the sound pine seed dispersed from the bumper 1948 seed crop at Bluesky remained undamaged at the time germination began in 1949. They also found that 40 percent (1,200 seeds per acre) of the Douglas-fir seed that fell from the poor crop in 1948 was available for germination the next spring. White-footed mice and chipmunks were blamed for most of this loss based on population counts and stomach analyses made on this area (Adams 1950). As this study continued, it was clear that most of the seeds that reached the ground were destroyed by mice, chipmunks, or other seed destroyers. The percent of seeds destroyed was always higher following dispersal of poor or medium crops.

During the 7-year period from 1949 to 1955, only 12 and 7 percent of the cumulative number of pine and fir seeds, respectively, survived until spring. This represented a total of only 14,000 pine and 20,200 Douglas-fir per acre.

Seed eaters on the Dunn and Butler plots were not effectively controlled by a single application of thallium sulphate-coated bait in early September of 1951. Initial control was obtained, but invading mice took most of the seed by the following spring. Although a few tree seeds probably were taken before poisoning, most were likely taken after the fall rains leached the chemical off the bait.

SEEDLING ESTABLISHMENT

Natural regeneration is almost always benefited by mineral soil seedbeds where competing vegetation has been reduced by scarification, burning, or with chemicals. Removal of competition increases the amount of water available for young seedlings. This is particularly true for ponderosa pine that grows in the drier sites in western Montana.

Table 6.--*Types and locations of seedbeds tested for establishing natural regeneration*

Location	Year of treatment	Seedbed treatment				
		None (control)	Bulldozer scarifying	Athens discing	Broadcast burning	Hand piling and burning slash
Bluesky	1948	X	X	--	X	X
Warland	1948	X	X	--	--	--
Jackson	1948	X	--	--	X	--
Dunn and Butler	1951	X	X	X	--	--

Methods

The effectiveness of different types of seedbeds for establishing natural regeneration was tested in various combinations at several locations (table 6). Seedbeds were prepared by:

1. *Bulldozer scarification.*--Exposed some mineral soil, piled slash, and disposed of some unmerchantable Douglas-fir.

2. *Athens discing.*--Exposed some mineral soil, but far less than by bulldozer scarification.

3. *Broadcast burning.*--Removed accumulations of logs and slash from the base of seed trees before treatment.

4. *Hand piling and burning.*--Exposed mineral soil only where the slash piles were burned.

A total of 730 systematically located milacre quadrats were established on the five seedbed conditions shown in table 6.

Results

Ponderosa pine was clearly a seral species on these study areas as demonstrated in the following tabulation of advance regeneration on untreated plots:

	Seedlings per acre (Number)	*Stocking (Percent)*
Ponderosa pine	51	4
Douglas-fir	1,415	48

The 1948 seed crop was responsible for nearly all of the pine regeneration during the 5-year study period at Bluesky, Warland, and Jackson. First-year results published by Roe and Squillace (1950) showed that the number of pine seedlings was about eight times greater on mineral soil (heavily scarified by bulldozer or on skid roads) than on duff when other conditions were similar. These data were derived from 700 of the 730 milacre plots plus an additional 241 temporary plots located on cutover areas at Bristow with larger numbers of seed trees. The number of pine seedlings per acre on mineral soil increased from 830 to 6,000 as the basal area of the residual stands went from 17 to 87 square feet per acre. Also, the distribution of pine became more uniform as the stand basal area increased. First-year stocking was satisfactory on mineral soil only in stands with over 40 square feet of basal area per acre. If rodents were controlled, stocking likely would have been adequate in stands with less basal area. Stands under 40 square feet of basal area ranged from 13 to 39 inches mean diameter and averaged 16 inches d.b.h. Stands over 40 square feet ranged from 16 to 33 inches mean diameter and averaged 23 inches d.b.h.

Initial survival of seedlings was far greater on heavily scarified seedbeds than on any other surfaces and this approximate percent of difference existed throughout the study period (fig. 4). By late June of 1949 more than five times as many pine seedlings were growing on heavily scarified seedbeds (primarily skid roads) as on duff at Bluesky, Jackson, and Warland (fig. 4); this is in contrast to nearly three times more than on burned seedbeds and almost six times more than on lightly scarified surfaces. It is not known whether these differences resulted from greater germination or less seedling mortality, or both, on the heavily scarified seedbeds. Mortality from late June through mid-October 1949 was low on all seedbeds because of above average rainfall from July through September. By early May of 1950 about half of the survivors died on seedbeds prepared by light scarification or burning and about one-fourth died on seedbeds prepared by heavy scarification or on duff. Frost heaving caused most of the pine seedling losses on burned and scarified surfaces in the early spring of 1950.

Five years after treatment, pine regeneration was still most abundant on the heavily scarified seedbeds (fig. 4). These surfaces maintained nearly four times more pine seedlings and three times greater stocking than on the other seedbeds. The numbers of seedlings counted in July 1953, stated as percents of the 1949 seedling count are as follows: 39 percent on burned seedbeds; 51 percent on untreated seedbeds; 55 percent on heavily scarified (skid road) seedbeds; and 60 percent on lightly scarified seedbeds. Most of the seedlings counted in July 1953 had germinated in May and June 1949.

At Bluesky, Jackson, and Warland, most of the Douglas-fir seedlings were established on all seedbeds prior to the beginning of the study. However, the only large increase occurred on heavily scarified seedbeds in 1953 following the heavy 1952 seed crop. All other seedbed treatments failed to enhance the initial survival of Douglas-fir.

Seedling establishment of ponderosa pine at Dunn and Butler from 1952 to 1961 was generally low, probably because of the lack of a receptive seedbed when seed was available. In addition, these plots were apparently established on the driest sites studied. Although from 200 to 7,000 pine seedlings per acre were established by 1961 on the seedbeds of both areas, poor seedling distribution resulted in an average of only 25 percent stocking 10 years after treatment. More pine seedlings became established on bulldozer scarified plots than on areas lightly scarified with an Athens disc or on duff. Additional pine seedlings became established at Dunn in 1954 and 1955 when the seed trees were banded with aluminum strips to prevent squirrels from climbing the trees and when the entire area was poisoned to decrease depredation by rodents.

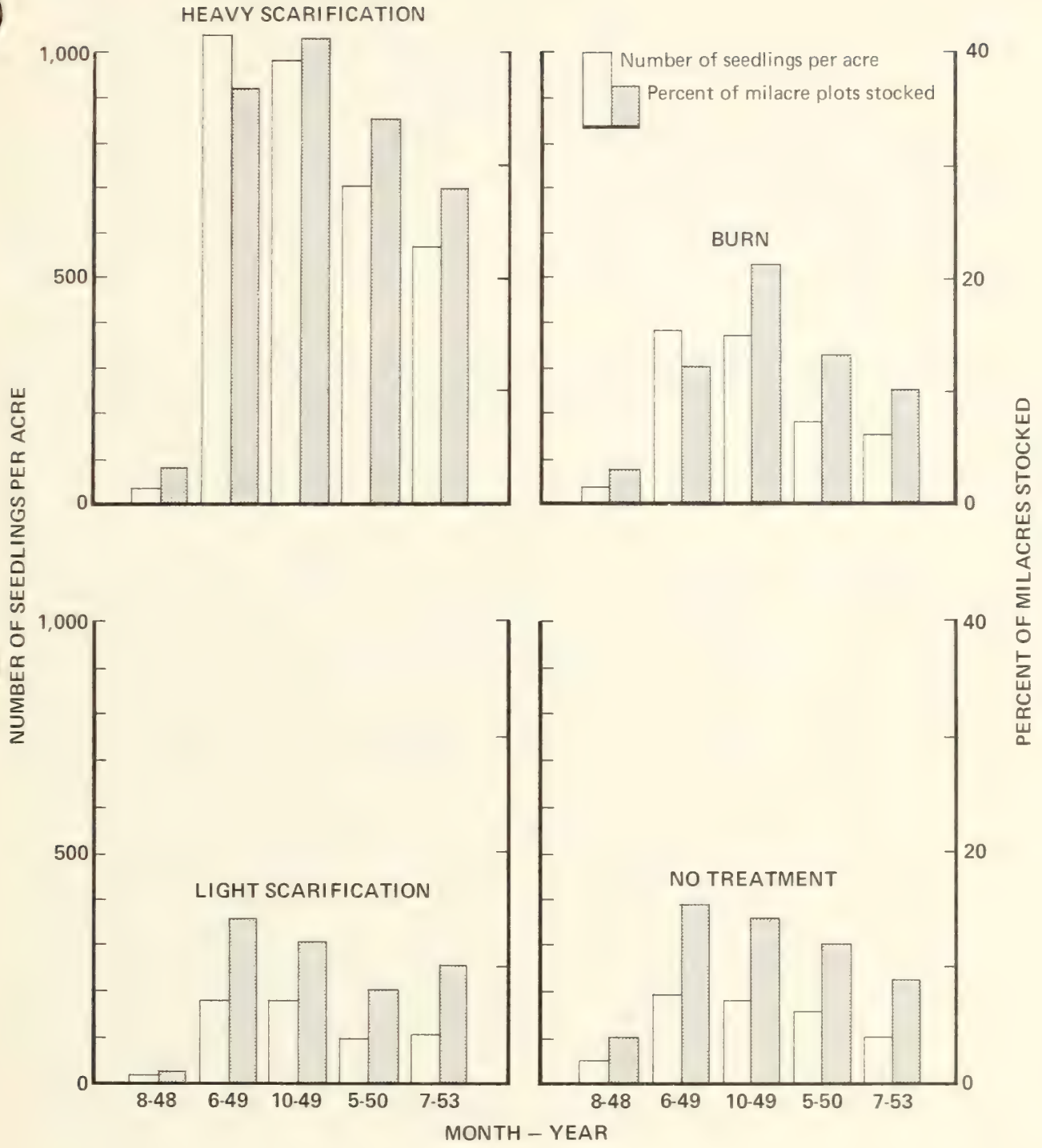


Figure 4.--Influence of seedbed on the regeneration of ponderosa pine by month and year. Open bars represent number of seedlings per acre; dotted bars are the percentage of milacre plots stocked.

Deer browsing was more common on pine seedlings growing at Bluesky than on those at Warland and Jackson. Douglas-fir seedlings were occasionally browsed. In the studies at Dunn and Butler deer damage on pine seedlings was 14 and 1 percent, respectively. Most of this damage occurred in the winter of 1953 and 1954.

DISCUSSION

Natural regeneration of ponderosa pine is spasmodic throughout its range except in the Black Hills (USDA Forest Service 1965). Successful establishment usually is dependent on: (1) adequate viable seed; (2) receptive seedbed; and (3) favorable climatic conditions during the first year. Of these three, the forest manager is able to manipulate the seed source and seedbed most easily. At present, little can be done to predict or influence climatic conditions, but through judicious control of seed source and seedbed the micro-environment around young seedlings can be enhanced during most years.

These studies quantify the effect of some physical and biological factors that limit seedling establishment in western Montana. Chief among these limiting factors are: (1) heavy losses of the potential seed crop during the 2-year cone development period; (2) heavy seed loss following dispersal; and (3) high seedling mortality. The odds are close to one or two in a thousand that a potential pine seed in the ovulate bud stage will become a surviving seedling. The additive effect of the above losses point to why it is difficult to successfully regenerate stands of ponderosa pine under normal conditions in most years (table 7).

The probabilities of establishing ponderosa pine seedlings are greatest when good seedbed preparation is coordinated with maximum seed production. Consequently, forest managers need to know as early as possible when a good crop of seeds can be expected. Factors that affect the initiation of ovulate buds as well as their subsequent development are not well understood. However, above average temperatures during the period of flower bud initiation (24 to 28 months before cone maturity) have been found to be closely correlated with good flower bud initiation and subsequent cone crops (Daubenmire 1960, Maguire 1956). Although it is unlikely that foresters will ever be able to predict cone crops with great accuracy, examination of the ovulate buds or first-year conelets can provide an estimate of the developing cone crop as much as 2 years before seed dispersal.

These studies have identified factors that drastically reduce the potential cone crop. Most of the first year cone losses resulted from abortions, but squirrels caused a majority of the second year losses. At present we do not understand the reason for the consistently high abortion rates and consequently can do nothing to reduce them.

Squirrels not only reduce current cone crops but future crops as well (Squillace 1953, Adams 1955). Squirrels usually sever the cone-bearing shoots just below the mature cones. This also eliminates any 1-year-old conelets or ovulate buds developing on the shoot beyond the cut. Also, such cutting may reduce the flowering potential for a few seasons. Squirrels also frequently cut shoots from the ends of branches in the winter to feed on the cambium layer, thus reducing still further the potential for cone production (Adams 1955). As a corrective measure, it may be necessary at times to place metal bands on seed trees in partially cut stands or in seed orchards to prevent squirrels from climbing (Tackle 1957, 1959).

Table 7.--*Theoretical 45-month development of cones, seeds, and seedlings from ovulate bud formation to the second year of seedling growth under normal conditions, compared with development using recommended management conditions*

Stage of development	Potential seedlings	
	Number	*Percent*
NORMAL CONDITIONS		
Ovulate buds (1,000)	[1]/80,000	100.00
First-year survival of conelets (270)	21,600	27.00
Second-year survival of cones (60)	4,800	6.00
Filled seeds after seedfall (75% of above)	3,600	4.50
Overwintering survival of seed (12% of above)	432	0.54
Surviving seedlings at beginning of second growing season (50% of above)	[2]/216	0.27
RECOMMENDED MANAGEMENT CONDITIONS		
Ovulate buds (1,000)	80,000	100.00
First-year survival of conelets (290)	23,200	29.00
Second-year survival of cones (200)	16,000	20.00
Filled seeds after seedfall (75% of above)	12,000	15.00
Overwintering survival of seed (50% of above)	6,000	7.50
Surviving seedlings at beginning of second growing season (50% of above)	3,000	3.75

[1]Based on 80 seeds per cone in mature, scattered stands in central Idaho[James D. Curtis and Marvin W. Foiles. Regeneration of ponderosa pine in the Northern Rocky Mountains. USDA Forest Serv., Intermountain Forest and Range Experiment Station, Ogden, Utah. (In preparation).]

[2]Based on 50 percent survival recorded for ponderosa pine from June 1949 to May 1950 in western Montana. This figure is probably high because of the favorable growing conditions that year. A closer estimate would be about 20 percent survival which occurred in 1959 in central Idaho (Foiles and Curtis 1965b) and from 1934 to 1941 in the Sierra Nevada of California (Fowells and Stark 1965). This would decrease the theoretical survival to 86 seedlings or 0.11 percent of the potential.

Other small mammals and birds also destroy ponderosa pine seed before it is disseminated (Curtis 1948). In addition, many insects such as pine seed moths (*Laspeyresia* spp.) or the ponderosa pine cone beetle (*Conophthorus ponderosae* Hopk.) infest the cones and seeds of this species (Keen 1958). During years of low production, insects may nearly destroy the entire crop of seeds.

Because good cone crops are infrequent, it may be desirable under some circumstances to stimulate cone production. The inherent genetic differences governing cone production presently preclude accurate predictions of which individual trees will respond to cone stimulation treatments. However, these studies indicate that girdling can stimulate production of ovulate buds for one season in about 80 percent of the 50-year-old pine trees. Older trees may respond to girdling also but stimulation will likely occur in only about one-half of the trees and the effect may be delayed a year longer than in the younger trees. These differences between young and old trees are probably due to the decreasing physiological activity associated with older age. Girdled trees recover rapidly from these wounds; stimulating effects are of short duration. Release did not increase cone production of the selected trees during the first two or three years; however, these trees may require several years to adjust to their new growing space before cone production is influenced.

Only the abundant seed years produce enough seed for germination and a level of survival that will assure adequate natural regeneration. Mice and chipmunks as well as other ground-dwelling mammals rely upon dispersed ponderosa pine seed for a significant part of their fall and winter diet. Attempts at control with one application of poison bait were unsuccessful here as well as in many other areas (Foiles and Curtis 1965b). Successful rodent eradication in Oregon required three applications of poisoned bait (Stein 1964).

Seeds that have survived the series of depredations up to the time of germination are potential seedlings, but as seedlings they will still face formidable survival barriers. In most years, competing vegetation reduces soil moisture to a level which is inadequate for survival of young seedlings.

Treatments that reduce competing vegetation and conserve soil moisture will promote seedling establishment in most years. Prescribed burning when fuels are dry, or heavy scarification in well distributed spots throughout a cutover area, offer two good choices for seedbed preparation. However, when an occasional heavy seed crop is followed by above average rainfall during the next growing season, as happened in 1949, some pine seedlings survive and restock many areas even though mineral soil may not be exposed (Pearson 1950, Foiles and Curtis 1965a).

Many old-growth ponderosa pine stands in western Montana grow on sites that are climax for Douglas-fir. As a result, most sites are usually well stocked with advance Douglas-fir seedlings. If the forest manager desires this regeneration, nothing more than some thinning and weeding is necessary to maintain these areas in a well-stocked condition. However, if he wants to establish ponderosa pine, the fir competition must be removed or drastically reduced.

In addition to the usual physical and biological factors limiting seedling establishment in western Montana, high deer populations in some localities frequently kill or severely browse the trees. Such browsing may occur until the trees are tall enough so the foliage is out of reach of these animals (Adams 1949, 1951a, 1951b).

SUMMARY

Several major factors influencing natural regeneration in ponderosa pine forests of western Montana were identified:

1. During the 2-year developmental period, cone production was decreased to 6 percent of the original potential. Cone abortions and squirrel cutting accounted for most of these losses.

2. Stimulation of cone production was largely unsuccessful although young trees did show a short-term favorable response to girdling.

3. Seedfall for both species began about September 1 and was nearly complete by the end of October. Weather conditions strongly influenced the time at which seeds were disseminated.

4. Seed overwintering in the duff was susceptible to large losses, primarily from rodents. Of the dispersed seed, only about 12 percent of the pine and 7 percent of the fir survived to germinate in the following spring.

5. Pine seedling establishment was greatest on heavily scarified seedbeds during the period studied but fir survived well on most seedbeds.

RECOMMENDATIONS

To successfully regenerate cutover ponderosa pine and Douglas-fir stands, the land manager must consider several alternatives. When thrifty advance regeneration of Douglas-fir is already established, it can usually be cultured to form a vigorous new stand, largely without pine. However, when restocking of ponderosa pine is desired, the most reliable method is planting on adequately prepared sites. Where natural regeneration of pine is desired, the following safeguards must be considered:

1. Protect seed crops from squirrels.

2. Reduce rodent population.

3. Time site preparation to coincide with predicted cone crops.

When any one of these recommendations are implemented, the land manager can expect a corresponding increase in the number of established seedlings and in the percent of milacres stocked. He can reasonably expect to control: (1) most squirrel depredations by banding the seed trees; (2) 50 percent of the seed losses on the ground by controlling seed-eating rodents; and (3) 50 percent of the first-year seedling losses by thorough site preparation. If this is done, then he may increase the number of surviving seedlings about 14 times as shown in the hypothetical example (table 9, "Recommended Management Conditions").

Successful application of all these recommendations could result in overstocking that would require thinning, especially in years with above average summer rainfall. However, land managers may want to take this gamble rather than risk inadequate stocking.

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AFLC/HAFB, Ogden

Headquarters for the Intermountain Forest and Range Experiment Station are in Ogden, Utah. Field Research Work Units are maintained in:

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